

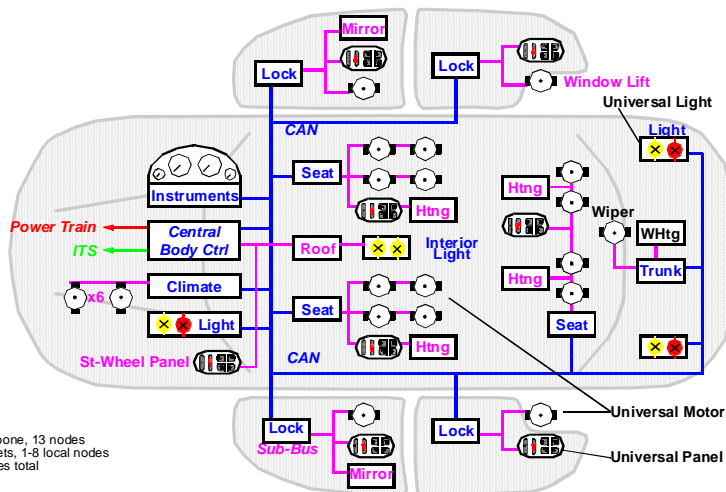
In-Vehicle Networking

Lecture 7 Introduction to CAN (Controller Area Network)
BAE 5030 – 353 / MAE 5483
Fall 2008
Instructors: Marvin Stone
Biosystems and Agricultural Engineering
Oklahoma State University

February 19, 2008

BAE 5030

Automotive Body Network



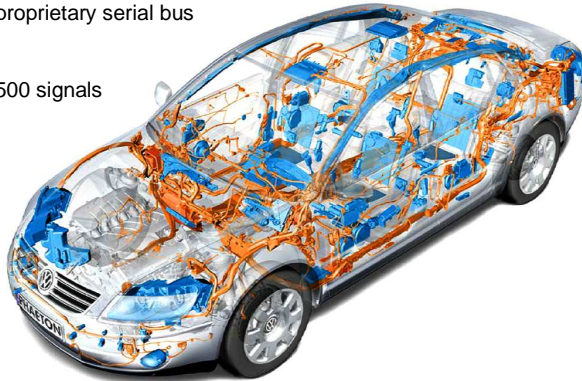
February 19, 2008

BAE 5030

Hierarchical networks are here today

VW Phaeton

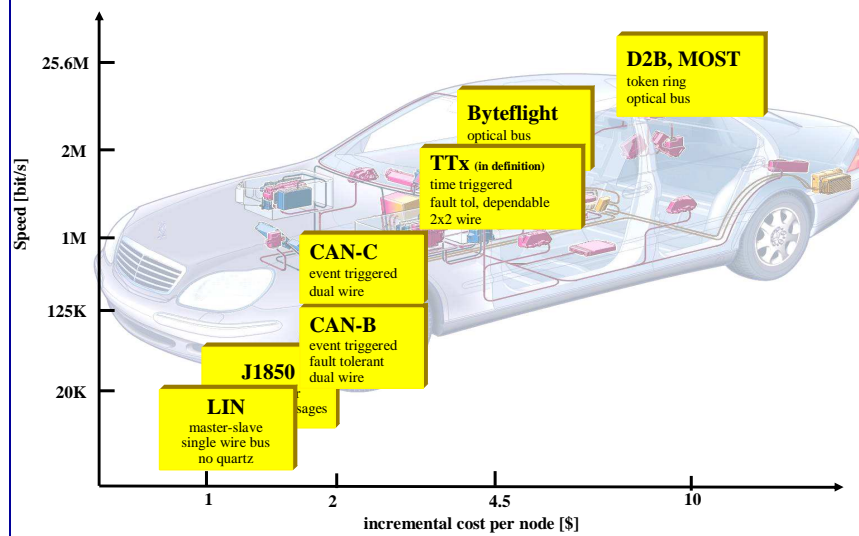
- Electrical parts: 11,136
- Communication: 61 ECUs in total
- External diagnosis: 31 ECUs via serial communication
- Optical bus for high bandwidth Infotainment-data
- sub-networks based on proprietary serial bus
- 35 ECUs connected by
- 3 CAN-busses
- sharing approximately 2500 signals
- in 250 CAN messages



February 19, 2008

BAE 5030

Costs and Speeds for Automotive Networks



February 19, 2008

BAE 5030

CAN

- CAN = Controller Area Network
 - Serial data communications protocol for real-time application using a multiple access bus
 - Messages have assignable priority
 - » most critical can dominate during heavy load
 - Messages are short (controlled length)
 - » opportunities to insert a new message come often
- Serial communications
 - Bus vs. Serial point-to-point
 - » Reduction in wiring complexity
 - » Better information sharing
- Low probability of an undetected error
 - 4.7×10^{-11} x message error rate
 - For a message error rate of 25/sec:
1 undetected error per 10,000 hours operation

February 19, 2008

BAE 5030

An overview of CAN based networking

- CAN - Elements
 - Message components
 - Identifier / Data
 - Bus Access - Arbitration / Prioritization
 - CSMA/CR
 - Bitwise priority access strategy
 - Non-destructive collisions
 - Error Detection / Error Confinement
 - Filtering
 - Other features
 - In Frame Acknowledgement
 - RTR

February 19, 2008

BAE 5030

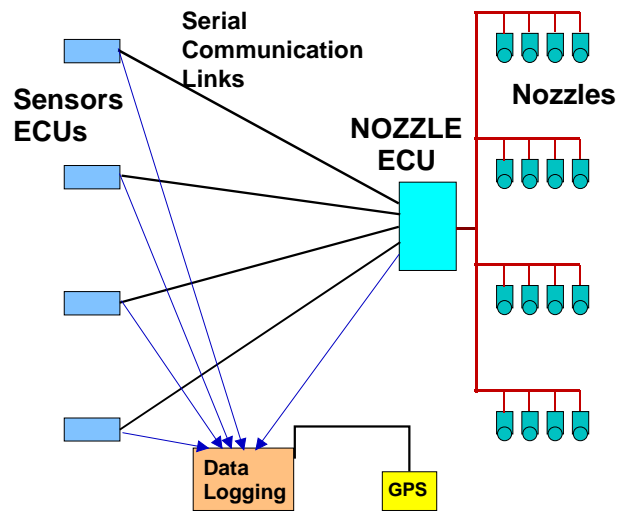
Harness Hell!



February 19, 2008

BAE 5030

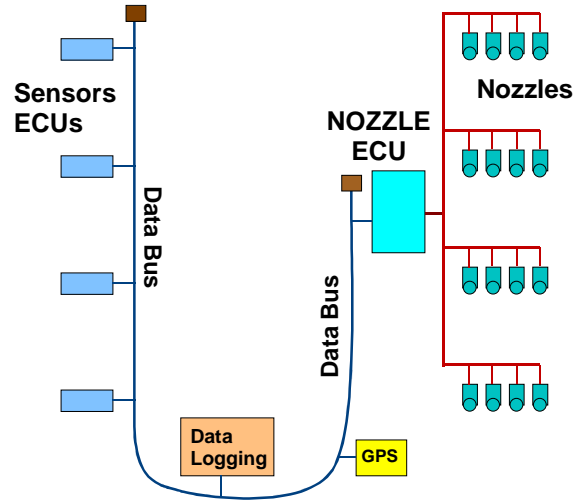
Conventional Wiring (No Bus)



February 19, 2008

BAE 5030

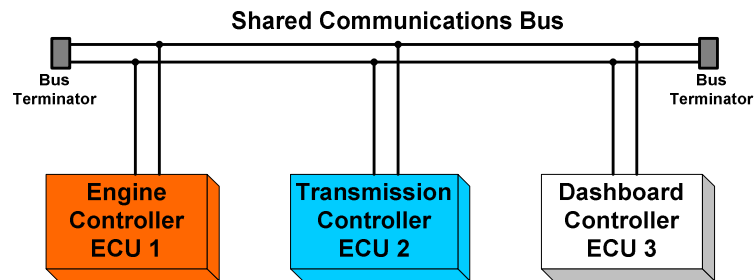
A Simple CAN Application (Serial Bus)



February 19, 2008

BAE 5030

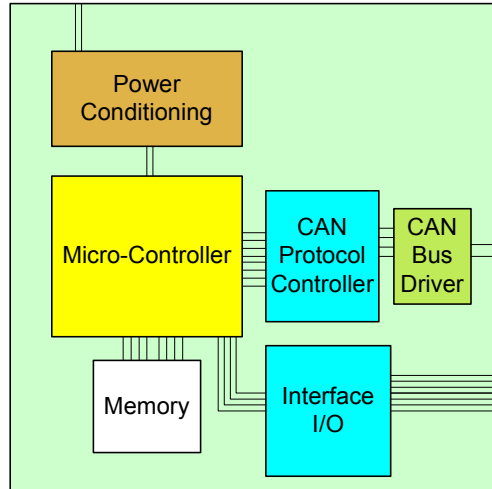
Communications Bus



February 19, 2008

BAE 5030

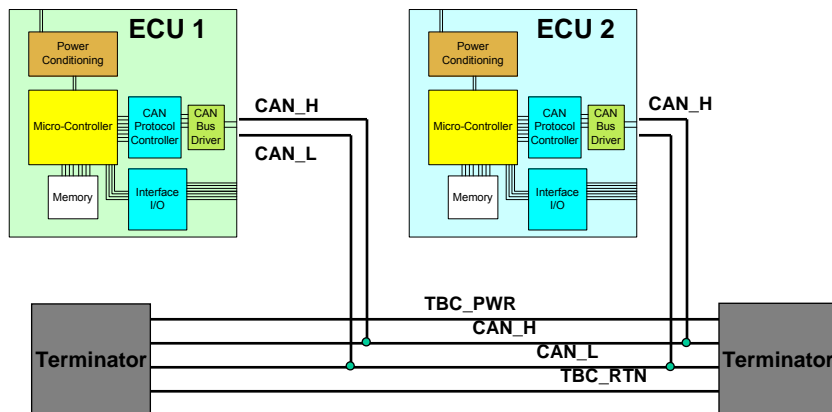
Typical ECU Components



February 19, 2008

BAE 5030

ECU Connection to the bus



February 19, 2008

BAE 5030

CAN - continued

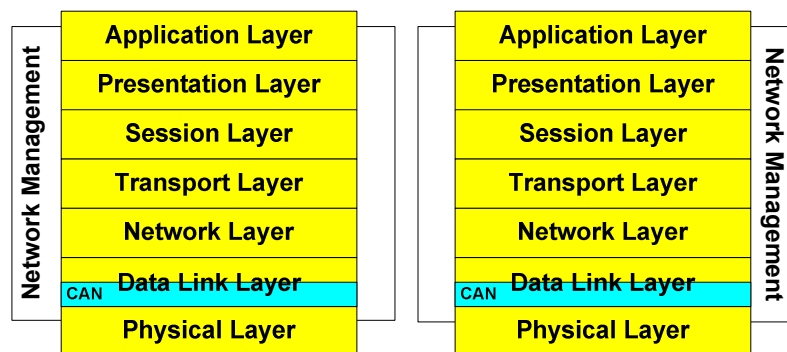
- Developed by Bosch GmbH
(See <http://www.semiconductors.bosch.de/pdf/can2spec.pdf>)
 - About 1986, Version 2.0 in 1991 for auto apps.
 - Version 1.2 (Equivalent to 2.0A)
 - 11 bit ID (not interoperable with 29 bit 2.0b)
 - Version 2.0 (2.0A + 2.0B)
 - 2.0B - 11 and 29 bit ID
 - » 11 and 29 are compatible on same bus
 - » 11 bit only 2.0B is called 2.0B passive
 - » 29 bit (and 11bit) 2.0B called 2.0B active
 - CAN provides only Data Link functions
 - Media access control
 - Logical link control

February 19, 2008

BAE 5030

Components of a “CAN Protocol”

To form a complete communications system you need more than CAN



ISO 7498 – Open Systems Interconnection (OSI)

February 19, 2008

BAE 5030

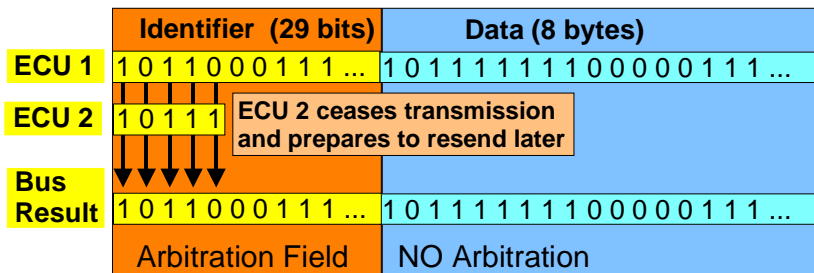
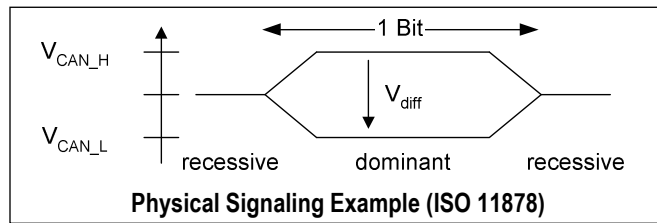
Network Protocols based on CAN

- SAE J1939
 - Heavy Duty Diesel Systems
 - On-Highway Truck
 - Agricultural Equipment
 - Construction Equipment
 - Generator Sets
- ISO 11783
 - Ag and Forestry Equipment
- NMEA 2000/IEC 61162-3
 - Marine / GPS / Navigation
- CANopen
 - Broad industrial applications - (CiA)
 - EN 50325-4
- DeviceNet
 - Industrial automation – PLCs (Allen Bradley)
- CAN Kingdom
 - Meta protocol - (Kvaser)

February 19, 2008

BAE 5030

CAN Arbitration



Lower numbered identifiers assume higher priority

February 19, 2008

BAE 5030

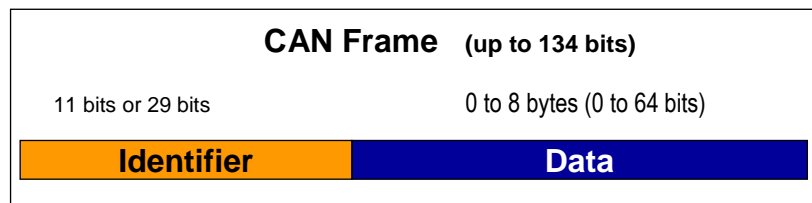
Consequences of identifier prioritization in CAN

- Unique Identifiers
 - Developer must assure all identifiers within a bus system are unique
- Resynchronization
 - CAN controllers assure message transmissions always start at the same time among controllers on the bus
- All messages queued are sent simultaneously
 - System appears to have one large queue where highest priority message is sent first

February 19, 2008

BAE 5030

CAN Frame Components



February 19, 2008

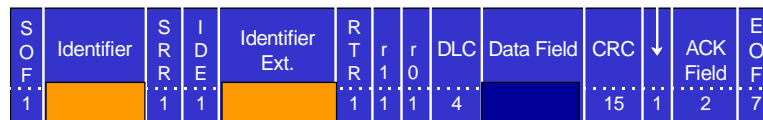
BAE 5030

CAN Frame Format - CAN 2.0B

CAN Frame (up to 134 bits)

11 bits or 29 bits

0 to 8 bytes (0 to 64 bits)



February 19, 2008

BAE 5030

Acknowledgement

- In-Frame acknowledgement
 - Any receiver of a message that receives a message correctly asserts a dominant acknowledge bit within the frame of the message being sent.
- Transmitter can know message was received by some receiver
 - Further message confirmation must be built at a higher level in the protocol
 - Transmitter alone on a bus will go bus OFF
- Receiver with an error
 - Transmits an error frame immediately after the message causing a Frame Error for all receivers

February 19, 2008

BAE 5030

Remote transmission request (RTR)

- Request message hardware feature
 - Allows setting a bit of an identifier to request a controller with a matching identifier to send the message
 - Can allow a response of a queued message without CPU interaction
 - Commonly not exploited in higher level standardized protocols

February 19, 2008

BAE 5030

Error Detection

- 5 Error Types Detected
 - Bit Error (Sent bit doesn't match monitored bit)
 - Stuff Error (more than 6 successive in one state)
 - CRC error
 - Form Error
 - Acknowledge Error
- Probability of an undetected error
 - 4.7×10^{-11} x message error rate
 - for a message error rate of 25/sec,
1 undetected error per 10,000 hours operation

February 19, 2008

BAE 5030

Message Filtering - Example

Accept if:
(ID AND MASK) XOR MATCH = 0

10111100100 IDENTIFIER 1 = Care, 0= Don't Care

11100000000 MASK

10100000000 = **ID AND MASK**

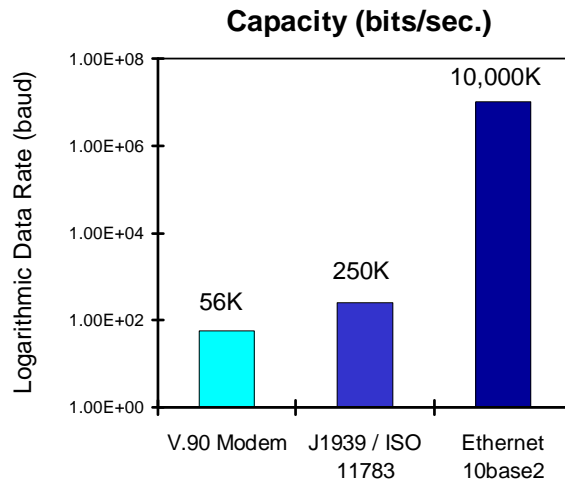
10100000000 MATCH Pattern must match

00000000000 = **(ID AND MASK) XOR MATCH**

February 19, 2008

BAE 5030

Capacity Comparison



February 19, 2008

BAE 5030

Capacity and Performance (Based on 250 KBaud)

- Use of bus bandwidth by messages
 - 100 messages per second (10 ms repetition) =5%
 - Torque/Speed control on engine
 - Hitch control
 - 10 messages per second (100 ms repetition) =0.5%
 - Throttle position
 - GPS Lat/Lon data
 - Implement application rate control (process data)
 - 1 message per second (1s repetition) =0.05%
 - Display updates
 - System status

February 19, 2008

BAE 5030

Message latency (Based on 250 KBaud)

- 134 bit message
 - @ $4\mu\text{s}$ per bit = $536\mu\text{s}$ = 0.5 ms per message max
- Highest priority message
 - must wait no more than ~0.5 ms
- Low priority messages
 - must wait till higher priority messages clear
 - latency may be long at high bus loads

February 19, 2008

BAE 5030

Bus Timing

- Bus bit rate is controlled by bit time
 - 1 MBaud \rightarrow 1 μ s/bit
 - 250 KBaud \rightarrow 4 μ s/bit
- Bit time is controlled by
 - Time Quanta (T_Q)
 - Bit segment settings (no. of T_Q per bit)
 - **Bit Time = $TQ * (Sync_Seg + Prop_Seg + Phase_Seg1 + Phase_Seg2)$**

February 19, 2008

BAE 5030

Bit Timing

- Each Bit Timing Segment is made up of integer units of time called Time Quanta (T_Q)



- User configures each segment to a specific number of T_Q
- Time allocated to each segment depends on CAN bus timing
- Bit Time can range from 8 to 25 T_Q
- AN754 “Understanding Microchip’s CAN Module Bit Timing”

Microchip CAN Seminar, 2006

February 19, 2008

BAE 5030

Propagation segment

- Twice the sum of Driver, cable , and comparator delay (See Microchip AN754)

- Propagation delay of cable $t_{prop} = 2 \cdot (t_{cmp} + t_{bus} + t_{drv})$
 - Typically 60-70% of c for 120 Ohm cables
 - Example: $v = \frac{1}{\sqrt{LC}}$

Nominal Velocity (%)	Velocity, Light (m/s)	Velocity, cable (m/s)	delay per meter (s)	Bus Length (m)	Bus delay (ns)
<i>n</i>	<i>c</i>	<i>v = nc</i>	<i>t = 1/v</i>	<i>l</i>	<i>d = 2lt</i>
60%	3.00E+08	1.80E+08	5.56E-09	40	2.22E+02

- Driver/Comparator delays – See datasheet
 - 50 ns

February 19, 2008

BAE 5030

Error handling

- Several different types of error frames are generated for protocol violations
 - ensures integrity of messages
- Act on faulty nodes (Fault Confinement)
 - CAN nodes can transition from working normally to being totally disconnected from the network based on fault data
 - Fault Confinement prevents faulty nodes from continuously transmitting and bogging down a network

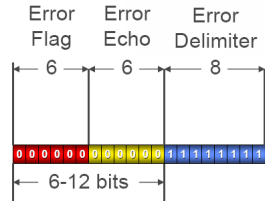
Microchip CAN Seminar, 2006

February 19, 2008

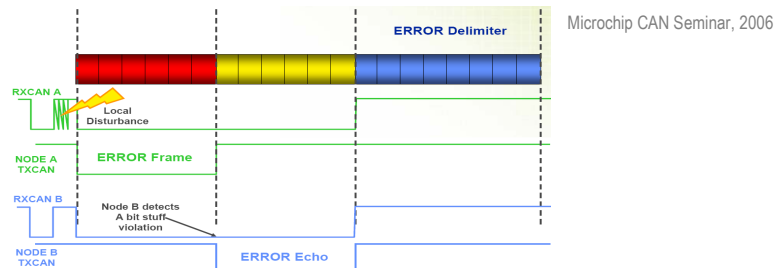
BAE 5030

Collaborative Error Frame Generation

- Error Frames are generated for any error detected by a CAN protocol controller



Superposition of Error Flags



February 19, 2008

BAE 5030

CRC errors



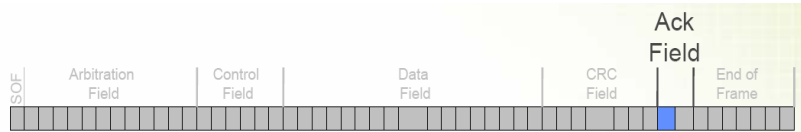
- CRC Error
 - 15-bit CRC appended in CRC field
 - All nodes receive message, calculate CRC and verify against CRC received
 - If CRCs do not match, a CRC error occurs and an Error Frame is generated
 - The transmitting node sees an error occur and re-transmits the original message

Microchip CAN Seminar, 2006

February 19, 2008

BAE 5030

Acknowledge Errors



- **Acknowledge Error**

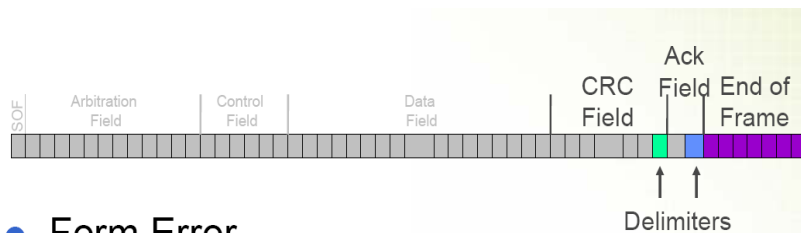
- Transmitting node checks the ACK Slot bit, which it has sent as a recessive and checks for a dominant
- If a dominant bit occurs, at least one node received the message correctly
- If not, an ACK Error occurred, an Error Frame is generated and the message will be repeated

Microchip CAN Seminar, 2006

February 19, 2008

BAE 5030

Form Errors



- **Form Error**

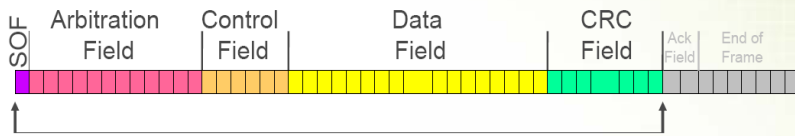
- Any node that detects a dominant in the CRC Delimiter, Ack Delimiter, End of Frame (EOF) field or Interframe Space generates an Error Frame for a Form Error
- The original message is then resent

Microchip CAN Seminar, 2006

February 19, 2008

BAE 5030

Stuff Errors



- **Stuff Error**

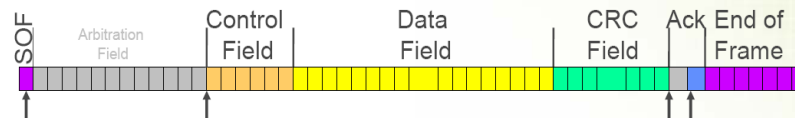
- If 6 consecutive bits with the same polarity are detected between the SOF and the CRC Delimiter, the bit stuffing rule has been violated
- An Error Frame is sent and the message will then be repeated

Microchip CAN Seminar, 2006

February 19, 2008

BAE 5030

Bit Errors



- **Bit Error**

- Occurs when the transmitter monitors a signal on the bus that is opposite of what it sent
- Exceptions
 - During arbitration (standard arbitration procedure)
 - In Ack Slot bit (due to valid message acknowledgement)

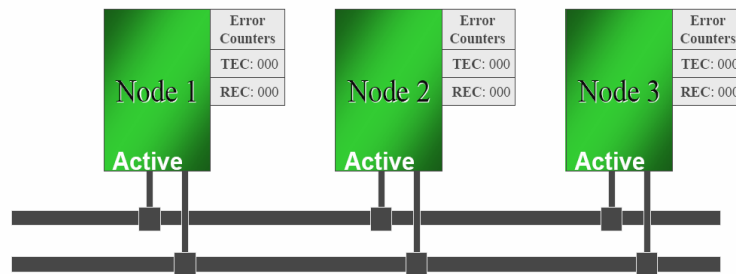
Microchip CAN Seminar, 2006

February 19, 2008

BAE 5030

System Fault Confinement

- Three Error States defined by CAN as a function of the error counters: Error Active, Error Passive, and Bus-Off
- Error Active is normal mode
 - Allowed to send messages and active error flags



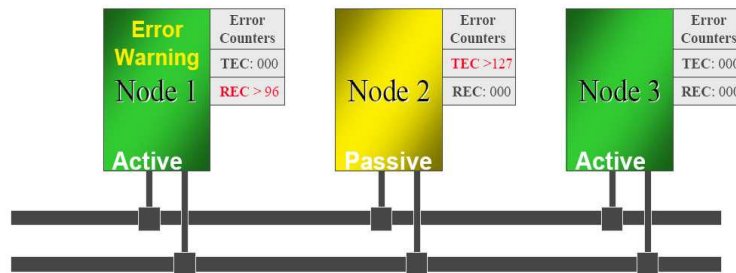
Microchip CAN Seminar, 2006

February 19, 2008

BAE 5030

System Fault Confinement

- When error counter exceeds 96, causes a warning interrupt
- When error counter > 128, node becomes error passive
 - Does not generate more error flags



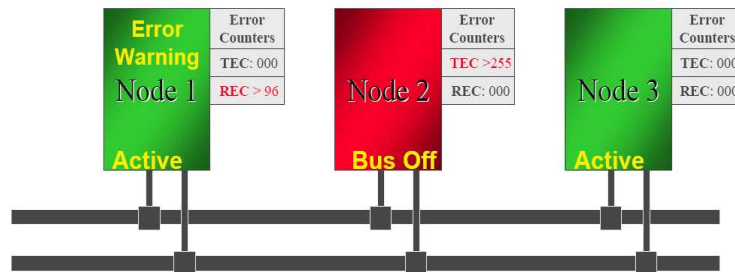
Microchip CAN Seminar, 2006

February 19, 2008

BAE 5030

System Fault Confinement

- When transmit error counter > 255, node becomes bus off
 - Cannot transmit any more messages
- Only transmitter (TEC) can cause “bus off”



February 19, 2008

BAE 5030

Microchip CAN Seminar, 2006